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ROBOT ASSISTED MATERIAL HANDLING  
FOR SHIRT COLLAR MANUFACTURING  
-- AUTOMATED SHIRT COLLAR MANUFACTURING --  
DLA 900-87-0017 Task 0014

FINAL REPORT

Volume I:

Executive Project Review and Summary

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## BACKGROUND

The research results summarized in this volume and detailed in Volumes II and III address work on computer controlled sewing and shirt collar band folding processes. This work was undertaken in conjunction with the Jet Sew Corporation as a subcontractor to build a special two axes computer controlled sewing head system and also a multi-station collar band folding machine for experimental evaluation. This equipment was developed in conjunction with Clemson University and evaluated in the Robotics and Machine Automation Laboratory, Clemson University.

The objective of the work on the two axes computer controlled sewing head system was to evaluate the process of sewing at velocities up to 7.5 inches per second by moving the sewing head using commercially available closed loop controllers. The results of this work is summarized below and the detail research results presented in Volume II of this final contract report.

The objective of the work on collar band folding was to understand the process mechanics of folding a variety of cloth materials and demonstrating the viability of this approach using a mechanical pressing and a superheated water vapor schemes. The complete results for these two processes can be found in Volume III of this final contract report.

## COMPUTER CONTROL OF SEWING MACHINE

### Introduction

A prototype two axis belt driven CNC sewing machine was designed and built for collar band and collar joining in the apparel manufacturing industry. This machine was built by the Jet Sew Corporation under subcontract to Clemson University. The machine was designed such that the sewing head translated in the horizontal X and Y axes. These two motions were actuated with brushless servomotors driving flexible belts attached to X and Y motion carriages which held the sewing head. The X axis length of motion was designed to accomodate various size apparel parts such as shirt collars, pockets and sleeve cuffs.

The research objectives were to evaluate the dynamic performance of the sewing system using analysis and experimental methods, and propose improvements to the system design which would improve the high speed path tracking ability of the sewing head.

#### Jet Sew Stitching Machine Design

The Jet Sew sewing system design was to be capable of sewing at a velocity of 7.5 inches per second with a needle speed of 75 stitches per second and maximum stitch length of 0.1 inches. The sewing velocity was to be maintained to within plus or minus 5 percent of the commanded value and be capable of acceleration/deceleration of 280 inches per second squared. The stitch positioning accuracy was to be within plus or minus one-half millimeter (0.02 inches) of the commanded path position.

The two axis machine was designed to carry the moving sewing head on orthogonal belt driven carriages, supported using a structural box beam frame. The machine was configured to provide a variable X axis stroke length to handle a variety of garment sizes. Most CNC stitchers used in the apparel industry do not have this advantage.

#### Machine Performance

The quality standards in the apparel industry require that each stitch in sewn garments be placed within plus or minus one-half millimeter of the commanded stitch path, with the stitch length within 5 percent of the commanded spacing. This constraint is relaxed at sewn corners where changes of path direction occur, permitting non-uniform stitch locations for two stitch lengths on either side of the direction change. With a constant stitch speed of 75 stitches per second and a velocity of 7.8 inches per second, this requires the sewing machine to be capable of accelerating (decelerating) at a rate of 281 inches per second squared. The Jet Sew stitching machine system was evaluated by tracking a sewing path composed of two orthogonal corners with a 2.5 inch straight line path between the corners.

Analytic models were developed for the two axis sewing system from basic principles and experimental frequency response measurements. Nonlinearity associated with motor current limiting (saturation) was included in the models developed for control system analysis. The frame support

structure also demonstrated vibrational coupling between the

X and Y axes which influenced the complexity of the required dynamic models.

The prototype stitching machine system was experimentally evaluated by commanding the sewing head to follow the desired path contour containing the two orthogonal corners. The corning action of the sewing head showed overshoot of the actual system path of 2 millimeters in the X axis and 1.5 millimeters in the Y axis. These results compared favorably with values obtained from the nonlinear model simulation of 1.78 millimeters (X axis) and 1.3 millimeters (Y axis). Differences in the modeled and experimental machine behavior can be attributed to unmodeled higher order dynamics and nonlinearities. These resulting dynamic errors in path tracking accuracy do not meet the desired performance specifications of the stitching machine system.

Changes in the machine and controller design are necessary if the Jet Sew stitching machine system is to meet the desired performance specifications. One mechanical design approach is to reduce the mass of the moving sewing head by utilizing a lighter sewing head or by moving the sewn material using the X-Y orthogonal motion axes and fixing the sewing head. A further improvement can be obtained by increasing the stiffness of the belt transmission used for reducing the servo motor drive speed. This may be achieved by using steel reinforced belts or ball screw transmissions. A further design modification requires that the structural frame needs to be stiffened to reduce the dynamic vibrational coupling between the X and Y orthogonal motion axes. Improvements can also be achieved by using a computer controller which does not have a fixed structure control algorithm, but can be programmed to achieve a variety of controller motion objectives and actions.

## FOLDING OF COLLAR BANDS

### Introduction

Collars on dress shirts incorporate a collar band which is sewn between the collar and the shirt body. This collar band consists of an inner face and an outer face which are contoured to match the shape of the collar on one edge and the shape of the shirt body on the other edge. A collar band is normally about 35-40 mm wide, and is the length of the neck size of the shirt. The collar is placed between the

inner and outer faces on one edge of the band, and the shirt body is placed between the inner and outer faces on the other edge of the band. Each edge of the collar band is sewn to fix the collar to the shirt body. Several minutes or even several days prior to the sewing of the collar band to the collar and to the shirt body, each edge of the collar band is folded to eliminate exposure of any frayed fabric edges. The fold, which is normally made with approximately 7 mm of material, must remain flat until the collar band is used during the assembly of the collar. Currently a layer of fabric impregnated with an adhesive is used to maintain the fold in the collar band. This interliner adheres the edge fold to the body of the collar band and maintains the flat fold over long periods of time. However the interliner increases the cost of the shirt and produces a bulky collar band. Thus a process which would allow the folding and fixing of collar bands without the use of these adhesive interliners would not only decrease production cost but also increase the quality of the shirt collar band.

The objectives of this research were to: (1) establish the parameter set (temperature, moisture, pressure, and time relationships) for folding and holding the fold in woven fabrics, and (2) design, build and compare two test apparatuses to illustrate the folding process.

#### Preliminary Laboratory Fabric Evaluation

Since the objective addressed folding fabrics used in the manufacture of dress shirts, only cotton/polyester blends were considered. A search of the literature revealed no comprehensive data set of parameter ranges or even the parameters to be used in folding. Hence, a test fixture was designed and built to determine the parameters required to achieve successful folds in woven fabrics. Experimentation with a limited set of cotton/polyester fabrics established the parameter set and the ranges needed for folding. Moisture is needed to relax cotton fibers to allow ceasing, then heat is needed for moisture retraction. Polyester fibers need only dry heat to raise the temperature above the heat-set temperature and then cooling of the fibers to maintain folded. Blends of cotton and polyester require various amounts of heating, moisture addition, moisture retraction and then cooling for adequate folding. Pressure is required during heating, moisture addition and retraction, and cooling to fold some fabrics with sizing or other finishes. These parameter ranges have been quantified and are presented in the attachment. Table I summarizes the required parameter ranges for the folding process as obtained from the test fixture.



Table I. Design Parameters for a Successful Crease

Material	Moisture Addition	Heating Temp (F)	Pressure
100% Cotton	yes	400	no
100% Cotton Crease Resistant	yes	400-410	yes
50/50 Cotton/Polyester	yes	360-370	no
100% Polyester	no	350-375	no

#### Concept Prototypes

The quantitative ranges of the folding parameters obtained from the test fixture were used as guidelines in developing two proof-of-concept apparatuses, one by Jet Sew in Barneveld, NY, and one by Clemson University, in Clemson, SC. Jet Sew developed a mechanism with conductive heating and cooling, and Clemson University developed a machine with convective heating and cooling. These mechanisms were then used to fold woven samples of 100% cotton, 35% polyester - 65% cotton (35/65), 55/45, 70/30, and 100% polyester. A presentation of these two apparatuses and the results which were obtained follows.

#### CLEMSON DESIGN:

The apparatus designed by Clemson University used a single folding chamber into which the fabric to be folded was placed. Superheated steam was used to provide convective heating, moisture addition and moisture retraction. An influx of steam onto the folding mechanism, whose temperature was below the steam saturation point, produced condensation and moisture for wetting the fabric. As steam continued to flow, the steam heated the fabric and the folding mechanism above the saturation temperature of the steam and evaporated the condensed moisture and dried the fabric. The steam flow was then diverted from the manifold, and room air was passed through the cloth and steam manifold to cool the fabric and the mechanism. Finally the folded fabric sample was removed from the folding unit. A complete description of this folding apparatus with photographs is given in the

attachment.

#### JET SEW DESIGN:

As shown in the attachment, the Jet Sew design was composed of five stations, each used to perform one of the following operations on the fabric sample: loading, folding, conductive heating, conductive cooling, and unloading. Heating and cooling were accomplished using metal blocks into which heating or cooling elements were inserted. The temperatures of the heating and cooling blocks at the start of each cycle, folding pressure, folding cavity temperatures, and cycle times were documented for each type of fabric tested and are presented in the attachment.

The same blends were used with both the Clemson and Jet Sew mechanisms. In cases where moisture was required in the Jet Sew device, the moisture was added manually to the fabric prior to loading the fabric at the loading station.

#### Comparison of Results

The limiting values of the folding parameters (those required for a satisfactory fold) are given for comparison in Tables II and III. It appears that the Jet Sew device was more suited to folding fabrics containing higher polyester content, while the Clemson device was more suited to folding fabrics of high cotton content. For the case of 100% cotton fabric, cycle times for the Jet Sew device ranged from 80-111 seconds in producing marginally acceptable folds, while the Clemson device produced optimum folds in as little as 28 seconds.

The Jet Sew device had no provision for moisture addition, thus moisture had to be added manually for the Jet Sew device to successfully fold fabric samples containing a high cotton content. Note from Table II that folding temperatures for the Clemson device were markedly different than those for the Jet Sew device. The Jet Sew device employed the more conventional means of conduction (pressing), and the folding temperatures were comparable to those reported for conventional ironing temperatures. In using superheated steam, the temperatures required for folding were nominally lower than those reported for conventional ironing. It should be noted that the values of the folding parameters varied depending on the fabric and also the method of heating, cooling, moisture addition, etc.

Table II. Limiting Values of Folding Parameters for  
Clemson Device

Material	Moisture Addition	Heating Temp (F)	Cooling Temp (F)	Pressure (psi)
100% Cotton	17%	338		25
65/35 Cotton/ Polyester	14%	360	305	26
55/45 Poly./ Cotton	13%	348	298	25
70/30 Poly./ Cotton	13%	344	290	26
100% Polyester	0%	310	292	25
Uncer- tainty	+/- 0.22%	+/- 2.75°F	+/- 2.75°F	+/- 2.1psi

Table III. Limiting Values of Folding Parameters for  
Jet Sew Device

Material	Moisture Addition	Heating Temp (F)	Cooling Temp (F)	Pressure (psi)
100% Cotton	24%	230	150	20
65/35 Cotton/ Polyester	21%	230	160	20
55/45 Poly./ Cotton	--	220	170	20
70/30 Poly./ Cotton	--	200	150	20
100% Polyester	--	200	160	20
Uncer- tainty	+/- 0.22%	+/- 2.75°F	+/- 2.75°F	+/- 2.1psi

The cost of operation of each unit was comparable. The major operating cost was due to the power consumption for heating the hot blocks in the Jet Sew device, and for producing and superheating the steam in the Clemson device. The estimated steady-state power consumption was 1.5 to 1.75 kW based on the cartridge heaters that were chosen for use in heating the hot block on the Jet Sew device or for the degree of superheat in the steam used in the Clemson device. With the existing information and since the cost of operation and construction would be similar, the selection of a device could be made objectively only on the basis of cycle time.

With the manual addition of moisture, it was possible for the Jet Sew device to fold the entire range of cotton/polyester blends. It may also be possible, upon further investigation, to modify the Clemson design to better accommodate those fabric blends with a high polyester content. Since the Clemson device successfully folded 100% polyester, it appears that only a slight modification of the existing machine would yield satisfactory results. One obvious means of improving the Clemson device would be to devise a means of exhausting the superheated steam after it flows through the cloth. This would increase the safety of the device and help limit condensation which then would reduce the drying time. The Jet Sew device must also be made to accommodate moisture addition in order to successfully fold fabrics containing a high cotton content.

Both the Jet Sew and the Clemson devices were designed to be manually operated for test purposes, however, the devices could and should be automated in the production device. Each machine has been designed so that controls could be added in future models. The test data obtained indicates that the superheated steam technique should be considered for use in a production folding unit. This technique considerably lowered the cycle times for folding high cotton content fabrics relative to the conductive heating and cooling technique. Also, a more efficient method of cooling used in conjunction with the superheated steam technique should improve the mechanism's performance for those materials containing a high polyester content.

For this reason, the initial phase of continued research should include the investigation of further improvements to the cooling system employed with the Clemson device to determine whether or not the use of superheated steam could be further refined to be more efficient in folding high polyester content materials. The design of a marketable folding mechanism which does not use the adhesive interliner seems attractive based on the results obtained with the Jet Sew and Clemson devices.